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Economic impacts of biofuels deployment in Andalusia

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ABSTRACT

This paper aims to estimate the economic impacts of increasing the production capacity of the installed biofuel plants in Andalusia (southern Spain). A computable general equilibrium (CGE) approach is used to calculate the changes in the economic sectors' activity, in employment as well as in GDP and other macroeconomic variables relevant to biofuel plants in Andalusia under two distinct scenarios (i) based on an operating biodiesel plant (with 90 ktoe/year of installed capacity); (ii) upgrading to 2174 ktoe by 2013 in compliance with the regional 'Plan Andaluz de Sostenibilidad Energética (PASENER) 2007–2013'. Results show that compliance with the PASENER goal would increase the activity level of the economic sectors considered by 3.04%, the total induced employment generated would reach 167,975 equivalent full-time jobs lasting one year and the GDP would increase by 9.82%.

Contents

1. Introduction

Initiatives in EU countries to promote renewable energy sources have been justified for reason of environmental benefits – due to the abatement of green-house gas (GHG) emissions[1] – and for the security of energy supply. The Spanish renewable resources plan in force PER (2011-2020) [37], sets a target for 2020 to achieve a minimum quota of 20% of energy from renewable

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[1] For the European Commission, by switching to renewable energies, the EU could cut consumption of fossil fuels by 200–300 m tonnes per year and reduce CO_2 emissions by 600–900 m tonnes a year.

Table 1
GHG emissions in life cycle of different types of fuels (g CO_2 equiv/km).
Source: Ciemat [14].

	CO_2	N_2O	CH_4	Total GHG
Conventional fossil diesel (Diesel EN-590)	157.92	4.45	0.875	163
Mixing of diesel with 5 % of biodiesel (BD5)	151.76	5.62	1.01	158
Mixing of diesel with 10 % of biodiesel (BD10)	145.6	6.8	1.15	154
Biodiesel 100 % (BD100)	38.06	29.2	3.59	71

sources in gross final energy consumption, and a minimum quota of 10% of energy from renewable sources of energy consumption in the transport sector, according to Directive 2009/28/EC of the European Parliament and of the Council of 23 April 2009 on the promotion of the use of energy from renewable sources.

Table 1 considers GHG emissions originated in production, transportation and use of four types of fuels. The data shows that the biodiesel production and consumption have a significant impact on the abatement of GHG.

The production and use of 100% biodiesel of vegetable oils (BD100) avoids the emission of 120 g of CO_2 for every km crossed in comparison with the production and use of diesel of fossil origin (EN-950), which supposes a saving of 76%. The effects of the mixtures are minor and have been included for a sensibility vision.[2]

Taking into account the emission of all the GHG is obtained that, the production and use of biodiesel of vegetable oils avoids the emission of 92 g of CO_2 equivalent for km crossed in comparison with the production and use of diesel of fossil origin, which supposes 57% of saving.

A remarkable take off of biofuels has taken place in Spain due to two main policy measures.

First, in order to raise the national quotas of biofuels used in transport, the EU authorities recommended the use of tax exemptions (European Council (EC) [18]/96/CE Directive). All the EU-27 members have introduced total or partial exemption of biofuels in their national specific taxes on fuels. Spanish authorities did this in 2002 by the Special Tax on fuels.

Second, the Spanish Industry Department has fixed the national quota of biofuels[3] in the total fuel used in transport at 1.9% for 2008,[4] at 3.4% for 2009 and at 5.83% for 2010.

These two policy measures generated great interest in biofuels technologies among investors. Particularly, interest by the Andalusian industry has been reinforced due to the regional authorities, promotion of renewable energies. In Andalusia, the promotion of renewable energy is the so-called 'Plan Andaluz de Sostenibilidad Energética (PASENER) 2007–2013'.

In spite of the Global Financial Crisis (GFC) it is expected that compliance with PASENER's goal increase by 2174 ktoe by 2013 from the 2007 installed capacity.

The purpose of this paper is to estimate the economic impacts that would derive from constructing biodiesel plants in Andalusia. Several reasons made biodiesel more attractive than bioethanol in Andalusia. First, the large number of diesel vehicles in Spain.[5] Second, a far greater number of gas-stations that sell biodiesel compared with those that sell bioethanol.[6] Third, the much higher number of operating or projected biodiesel plants in Andalusia compared with the number of bioethanol plants.[7]

Although general equilibrium models have been used to analyze energy questions from an economic point of view, the economic impact of renewable energies has been usually estimated by using input–output models.[8] For example, for the USA economy, input–output analysis has been used by Cook [16], U.S. DOE [53] and Ciorba et al. [15]; for the European area Kulisic et al.; Madlener and Koller [28,29]; and Allan et al. [3], developed a similar approach. Caldés et al. [9], Calzada et al. [10] and European Commission (MITRE) [19], recently used an input–output model to estimate the economic impact of renewable energies in Spain.

This work aims to expand the literature in three ways: first, by gathering cost data on the construction, operation and maintenance of operating biodiesel plants. Second, by using a CGE model, based on a Social Accounting Matrix (SAM) instead of the input–output models that have been used in similar works. And third, the CGE model allowed us to analyze two types of economic impacts:

(i) Direct impacts caused by the expansion of production in other activity sectors that need intermediate inputs of the manufacturing process from a branch of activity. In this case, the construction, operation, maintenance and dismantling of a biodiesel plant requires inputs of other activities and this requirement causes effects on production.[9]
(ii) Induced impacts that occur in the productive structure, derived from the productive cycle by the relationships between consumption and intermediate demand among activity sectors. To satisfy the input requirements of the biodiesel plant, remaining activities require other inputs. The use of the SAM also allows us to capture the effects from the generation of income that assumes a circular flow of income. The production of each activity generates a feedback process from the income of the production factors through to the expenditure of the institutional sector and finally to each activity's own productive process.

This paper focuses on estimating both the direct and induced impacts on the economic sectors' activity as well as other macroeconomic variables.

Over the past 25 years, the CGEs models have been widely used to analyse government economic policies, both in developed and developing countries[10] (Shoven and Whalley [47]). In general terms, these models translate the theoretical Walrasian general equilibrium system into fully operational tools, including an endogenous output and price system, substitutability in production and demands, and the optimization behaviour of individual agents. A CGE model allows to study the changes in the spheres of production and consumption, as well as in income distribution, in response to changes in a given economic policy, as these models explicitly include a representation of the framework of interdependencies among all markets in an economy. A Static Computable General Equilibrium Model is applied in this paper. The aim of this approach is to simulate all sectors of an economy where the changes in the technology are very slow. This approach captures

[2] A previous research has explored the economic potential of biofuels in a greenhouse gas mitigation market by incorporating data on production and biofuel processing in U.S. This paper came to the conclusion that subsidies are needed to make agricultural biofuel production economically feasible. See Schneider and McCarl [45].

[3] See article 4 of O ITC/2877/2008, October 9.

[4] Only for 2009 and 2010, the quotas are mandatory.

[5] In 2007 the distribution of the consumption of fuels for transport was 79.5% for diesel oil and 20.6% for petrols; vide [48].

[6] With data taken from energias-renovables.com in Spain, there are 487 gas stations selling biodiesel and 9 serving bioethanol.

[7] See AAE [1].

[8] However, a previous research employed a CGE model in the Austrian economy to quantify the impacts of fostering the use of distinct biomass energy technologies (Steininger and Voraberger [49]).

[9] Due to the lack of actual data regarding the dismantling phase of the project, this last phase will not be considered in the paper.

[10] See, recently, Arndt et al. [4].

the real effects in short run and middle run. We are aware about the limitations of this one – with their advantages and disadvantages – as what happens to other approaches (i.e. a Dynamic CGE or an Input–Output approaches).

In order to estimate the economic impacts in Andalusia, two different scenarios have been considered:

(i) The first scenario considers the individual impact derived from the construction and operation of one biodiesel plant with 90 ktoe/year installed capacity.
(ii) The second scenario considers the PASENER installed capacity goal for biofuels production, which would lead to 2174 ktoe by 2013. It is assumed that this goal would be reached with existing biodiesel plants.

The structure of this paper is as follows. After this introduction, in the second section the modelling approach (CGE model), the database (SAM) and the biodiesel plant costs data that have been used are explained. In the third section, the results from the two scenarios considered – the individual impacts derived from a standard biodiesel plant and the associated effects of the PASENER's goal compliance – are shown and discussed. Finally, in the last section, the main conclusions are presented.

2. Modelling approach and data

2.1. CGE model and database (SAM)

A CGE model based on a SAM, has been used to analyze the economic impacts derived from the compliance with PASENER's goal. A CGE model involves a set of equations that reflect equilibrium conditions and the behaviour of the different economic agents in an economy. The structure of the CGE model is described in Annex I.

In order to study the effects of the biodiesel plants in the Andalusia economy, the SAM used for the modelling and computation is based on the Andalusian economy data (SAMAND). The most recent SAMAND dates from 2000 and it is due to Cardenete et al. [11] constructed from Andalusian Input–Output Tables dating from 2000 as basic source. This Matrix has been adapted for the year 2008, using the cross entropy method (CE),[11] and the overall available information on the production and GDP for this year. We refer to it as SAMAND08. The cross-entropy approach involves projecting technical coefficients instead of total SAM flows —as traditional method called RAS—. Cross-entropy aims directly at estimating technical coefficients. Therefore, with regard to standard RAS the difference is that CE uses technical coefficient matrices in the minimand instead of total flows.[12]

As for the degree of disaggregating of the sectors of the SAMAND08 is a 26×26 matrix, so it contains 26 accounts, where the flows realized in the Andalusian economy for the year 2000 are described. The productive sectors have been reduced to 14 (account numbers 1 to 14); plus two productive factors – labour and capital – are (15 and 16, respectively); the consumption (17); the saving/investment account is sector (18); and indirect taxes, employers' social security taxes, net taxes on production, tariffs and valued added tax (VAT); and direct taxes, income tax and employees' social security taxes are sectors (19 to 24); Public administration (25); and the last one is the foreign sector (26).

[11] For more information about the cross entropy method, see Robinson et al. [41].

[12] For more information about the discussion about CE and RAS methodology, see Cardenete and Sancho [13].

As it is shown in Table A1 and Table A2 in Annex II, total investment and operating cost of biodiesel plants have been broken down and associated with the different sectors included in the SAMAND08.

The data contained in the SAMAND08 is reproduced in a CGE model as a *benchmark equilibrium* in which all prices (endogenous and exogenous) are equal to 1 at the initial time. We have calibrated all parameters and elasticities using this SAM avoiding the external estimations of those ones with econometrics approaches. From this initial condition, the increase of demand associated with the biofuel sector implied in the PASENER goal is introduced in the CGE model provoking an *exogenous shock*. This will allow us to evaluate the changes by comparing benchmark equilibrium with the simulation equilibrium. The model has been implemented using *GAMS* software (Brooke et al. [8]) with *MINOS* as the solver. It was also considered that during the period under consideration, the operating and investment costs would remain constant, although that might limit our conclusions underestimating or overestimating some benefits of developing such plants.

2.2. Biodiesel plant costs data

This paper is based on biodiesel production using pure vegetable oils from oily seeds (sunflower, rape, soybean and oil palms) cultivated “ex professo” for energetic purpose. The oil is surrendered to a process called “trans esterification” that hydrolyzes the ester bonds of the triglycerides and obtains new esters with fatty acids released by hydrolysis and a simple alcohol used as a reagent. The process takes place in the presence of a catalyst, usually sodium hidroxide or potassium hidroxide, and at moderate temperature of about 60 °C. Actually, this process is very close to the domestic soap production. In fact, during the production of biodiesel, the main compound of the soap is obtained, the glycerin, which is a by-product of high added value and with multiple commercial exits in the chemical, agrarian and food sectors. The productive process efficiency is high: from a ton of oil, 156 kg of methanol and 9.2 kg of potassium hidroxide, 956 kg of biodiesel can be obtained (hence, the process has a yield of 95.6%) and 178 kg of unrefined glycerin, besides recovering 23 kg of methanol.

The original data related to biodiesel plants have been provided by AAE [2]. Table 2 shows the details of the investment costs associated with a 100 Tm/year biodiesel plant equivalent to 90 ktoe/year: the ‘Reesterification plant and glycerin' accounts for 53.76% of the total investment cost, ‘civil construction’ for 15.18%, ‘Energy plant and boilers’ for 12.65%, ‘tanks and auxiliary equipment’ for 12.33%, and the remaining 6.08% accounts for the ‘terrain’.

In order to determine the operation and maintenance costs, an operational life of 20 years, an annual discount rate of 8% was assumed.[13] Both total annual operation and maintenance cost and other costs accumulated during 20 years are shown in Table 3.[14] The estimation of the financing expenses has been computed considering a 12-year repayment loan with a 5% interest rate.

Following Caldés et al. [9], the eighty per cent of the expenses related to the annual operation, maintenance and other costs of a biodiesel plant are salary costs. Additionally, according to the National Statistics Institute (INE) data, the average salary of a Spanish employee that works in sector 19.2 “Petroleum refining”[15]

[13] The Return-on-Assets (ROA) rate as in Calzada et al. [10] is assumed.

[14] For a broad perspective on some concepts included in Table 3, see Ryan et al. [43], Demirbas [17], and Peters and Thielmann [36].

[15] See Instituto Nacional de Estadística (INE) [24], Quarterly Survey of Labour Cost QIV. For sector 19.2 of CNAE09, every Full Time Employee (FTE) is employed 1800 h/year.

Table 2
Breakdown of investment costs per a biodiesel plant.
Source: Own elaboration.

Cost component	Investment (Thousand €)[a]	Investment (%)	% of imports in the cost
Energy plant and boilers	4,000	12.65	60
Civil construction	4,800	15.18	0
Reesterification plant +glycerin	17,000	53.76	75
Tanks and auxiliary equipments	3,900	12.33	30
Terrain	1,922	6.08	0
Total	31,622	100	

[a] Figures are expressed in 2008 euros.

Table 3
Biodiesel plant operation, maintenance and other costs.
Source: Own elaboration.

Cost component	Annual cost (Thousand €)[a]	Annual cost (%)	Total cost lifetime 20 years (Thousand €)[a]	Imports in the total cost (%)
Salaries	660.0	1.04	8,593.2	0
Assurances	70.0	0.11	911.4	5
Trans esterification maintenance	316.0	0.50	4,114.3	25
Financing	1,846.2	2.90	36,107.3	30
Vegetable oil	53,560.0	84.23	697,351.2	0
Methanol	3,724.4	5.86	48,492.7	0
Potassium Hydroxide	1,186.5	1.87	15,449.0	0
Sulphuric acid	245.1	0.39	3,191.7	0
Compressed air	721.0	1.13	9,387.4	0
Water steam	824.0	1.30	10,728.4	0
Electricity	432.6	0.68	5,632.4	0
Total	63,586.0	100	839,959.2	

[a] Figures are expressed in 2008 euros.

amounts to 49,115 €/year. From these data, the number of employees working annually in this plant has been estimated that would amount to 8.74 people.

Direct employment provoked by the PASENER compliance is generated during the lifetime of the plant. In the case of the type of plant considered in the paper, direct employment amounts to 4226.23 Full Time Employees (FTE).

The increase in the total direct demand associated with the construction and operating of the biodiesel plant amounts to 871,581.2 thousand €, which represents an annual demand of 65,978.9 thousand €/year (assuming a construction period of 18 months, a lifetime of 20 years and an annual discount rate of 8%). This direct demand can be expressed as a function of the size of the biodiesel plant, which amounts to 733,098 €/year for every ktoe installed.

The final capacity fixed in PASENER is assumed that comes from distributed plant across the regional land (87,597 km^2).

3. Scenario results

The CGE model developed allows us to estimate the economic impact derived from the two scenarios.

The first scenario considers the individual impact derived from the construction and operation of one biodiesel plant with 90 ktoe/year installed capacity. The operation of a biodiesel plant would generate an aggregated increase of 1.83% in the 14 sectors' production during the lifetime of the plant (20 years). Table 4 shows the associated effect of the biodiesel plant on every sector included in the SAMAND08. The highest impact occurs on sectors 1, 7 and 13, equal to 5.49%, 2.16% and 2.53%, respectively. Besides these sectors, there is also an important impact on sectors 5 and 6 – Electricity and Gas sectors – equal to 1.96% and 1.60%, respectively.

The indirect one-year jobs generated by the increased demand of goods and services in the Andalusian economy are calculated from the change in the unemployment rate. The variation rate in the unemployment rate multiply by the active population leads us to obtain the jobs generated by the initial shock. The amount of indirect one-year jobs is of 102,007 people.

The second scenario considers the PASENER installed capacity goal for biofuels production, which would lead to 2174 ktoe by 2013. The PASENER's goal compliance would generate an increase of 3.04% in the output of the 14 sectors considered during the lifetime of the plant. Table 4 shows the associated effect of the PASENER's goal compliance on every sector included in the SAMAND08. As expected, the highest impact occurs again on sector 1[16] equal to 24.66%. This result must be stressed because Primary Sector is an important one in the Andalusian economy with a percentage of almost 5% on total value added and an intensive use of human factor. Vegetable oil extracted from raw materials such as sunflower and rapeseed is the main raw material used in Andalusia for obtaining biodiesel. However, this sector shows a low multiplier effect. Future develops in advanced biodiesel from lignocelluloses could stress the role of the primary sector.

Besides sector 1, there is an important impact on sectors 5, 6 and 9 equal to 6.76%, 5.57% and 5.45%, respectively. Electricity is a relevant input in the structure of the O&M costs and gas is needed for Combined Cycle power plants. The impact on sector 9 is mainly due to the investment requirements for the new biodiesel plants.

The CGE model developed also show that the increased demand of goods and services in the Andalusian economy in this second scenario would generate an additional 167,975 one-year jobs. This is a relevant finding from a policy maker perspective due to the high unemployment level in this region.

The analysis of Table 4 shows that the multiplier effects of the Keynesian process depend on the productive sectors that have been used for the development of this shock. For instance, it is not the same the impact assessment of a sector with a low multiplier, as it happens with Agriculture sector, than a sector with high multiplier as it occurs with Transports and Communications sector.

Table 5 shows the impact on the other macroeconomic variables considered.

In the first scenario, the construction, operation and maintenance of a biodiesel plant would generate a positive effect on all the variables considered with the exception of the net indirect tax revenue and the total tax revenues. During the lifetime of the plant, the disposable income of the Andalusian economy would increase by 1.74%, the labour payments by 3.08% and Earnings before Interest, Taxes, Depreciation and Amortization (EBITDA) by 2.80%. The GDP-income also increases by 2.31%. Also, the effect on the direct tax revenues would be positive and equal to 1.74% although the net indirect tax revenues would decrease but only by 0.08%.

In the second scenario, the construction and operation of the PASENER's goal compliance would generate a positive effect on all

[16] To read more about biofuel sector and the agriculture sector, see Hayes et al. [23].

Table 4
Economic impacts considering two scenarios.
Source: Own elaboration. Figures are expressed in 2008 euros.

Sector code	Sector name	Original output level Andalucia economy (Thousand €)	Simulation output level Standard biodiesel plant (Thousand €)	Variation rate output level Standard biodiesel plant (%)	Simulation output level PASENER goal (Thousand €)	Variation rate output level PASENER goal (%)
1	Primary sector	12,563.0	13,253.1	5.49	15,661.5	24.66
2	Coal	2,855.6	2,893.7	1.34	2,956.6	3.54
3	Rest of extracts	2,590.4	2,609.6	0.74	2,710.4	4.63
4	Oil and natural gas	12,271.3	12,420.1	1.21	12,615.6	2.81
5	Electricity	4,706.4	4,798.8	1.96	5,024.4	6.76
6	Gas	506.2	514.3	1.60	534.5	5.57
7	Water	1,082.8	1,106.2	2.16	1,126.3	4.02
8	Food industry, textile and leather, wood products, chemicals and other manufacturing	65,679.0	66,432.1	1.15	66,777.8	1.67
9	Mining, iron and steel industry	5,580.4	5,613.2	0.59	5,884.6	5.45
10	Metallic products, machinery and vehicles	27,559.6	27,809.0	0.90	27,964.9	1.47
11	Building materials	7,208.8	7,261.5	0.73	7,489.5	3.89
12	Transport and communications and other transport elements	21,915.5	22,214.3	1.36	22,212.2	1.35
13	Construction, commerce and sales services	149,835.2	153,630.3	2.53	153,690.6	2.57
14	Non-sales services	26,174.9	26,198.3	0.09	26,220.9	0.18
Total		340,529.8	346,755.2	1.83	350,870.4	3.04

Table 5
Impacts on macroeconomic variables in the two scenarios.
Source: Own elaboration.

Macroeconomic variables	Variation rate (%) Standard biodiesel plant	Variation rate (%) PASENER goal
Disposable income	1.74	4.69
Labour payments	3.08	9.82
Earnings before interest, taxes, depreciation and amortization (EBITDA)	2.80	5.67
Net indirect tax revenues	−0.08	4.65
Direct tax revenues	1.74	4.69
Regional GDP	2.31	9.82

the variables considered as follows. During the lifetime of the plant, the disposable income of the Andalusian economy would increase by 4.69%, the labour payments by 9.82% and EBITDA by 5.67%. The GDP-income also increases by 9.82%. The effect on the direct tax revenues would be positive and equal to 4.69% and the net indirect tax revenues would also increase by 4.65%.

4. Conclusions

Together with its environmental benefits – mainly due to the abatement of GHG emissions – and fostering the security of energy supply, the public promotion of biofuel can be justified in terms of social welfare.

The data contained in the SAM is reproduced as a *benchmark equilibrium* in which all prices (endogenous and exogenous) are equal to 1 at the initial time. After provoking an *exogenous shock* in the model, the changes are evaluated by comparing benchmark equilibrium with the simulation equilibrium.

In the first scenario, the operation of a biodiesel plant would generate an aggregated increase of 1.83% in the activity level during the lifetime of the plant (20 years). In the second scenario, the installed capacity of PASENER's goal for biofuels production would lead an increase of 3.04% in the activity level. In both scenarios, primary sector reaches the highest impact (first scenario – 5.49% – and second scenario, 24.26%). This result must be stressed because Primary Sector is an important one in the Andalusian economy.

In first scenario, all macroeconomic variables with exception of Net indirect tax revenues increased. In the second scenario, all macroeconomic variables considered receive a positive impact. The induced employment generated is remarkable in both scenarios, but in the second would amount to 167,975 one-year jobs.

It can be concluded that the economic effects derived from the accomplishment of the PASENER installed capacity goal are remarkable in terms of the increase of the activity level of the economic sectors considered, particularly agriculture sector, the increase in direct and induced full time employment generated, the higher disposable income and the improvement in labour payments, EBITDA and tax revenues.

From the policy maker perspective, the positive economic impacts achieved must be considered jointly with the environmental ones. Although the assessment of the last ones is not the purpose of this research, two of the main ones need further consideration. First of all, the indirect land use change (ILUC) issue has been pointed out from seminal paper of Searchinger et al. (2008) [46] and recent contributions debt to Gawel and Ludwig (2011) [22], Kim and Dale (2011) [27], O'Hare et al. (2011) [35] and Broch et al. (2013) [7] Second, glycerine is produced in large quantities as a by-product of biodiesel process. Sustainable biodiesel production requires optimization of its production process and drastic increase in the utilization of glycerol. Although the sale of glycerine to pharmaceutical industry is not currently feasible because of the quality of this by-product, several studies have addressed identification of possible uses for it (Ayoub and Zuhairi-Abdullah, 2012 [5]; Bevilacqua-Leoneti et al., 2012 [6]). The

possibilities include the production of fuel additives (McNeil et al., 2012 [30]), hydrogen (Öncel Özgür and Zühtü Uysal, 2011 [34]), biogas (Robra et al., 2010 [42]), 1,3-propanediol (1,3-PD) and ethanol (Misturini-Rossi et al., 2012 [32]; Peralba et al., 2012 [38]; Metsoviti et al., 2013 [31]) among others. However, glycerine supply currently exceeds its demand by a significant margin.

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Annex I

The social accounting matrix (SAM)

The beginnings of the analysis with Social Accounting Matrices can be found in Stone [50], and Pyatt and Round [40] among others, having its first applications in Spain in works such as Kehoe et al. [25]. Recently, SAMs have also been developed at a regional level in Spain as in Polo and Sancho [39]; Uriel et al. [52]; Fernández and Polo [20], Uriel et al. [51]; Cardenete and Sancho [12]; and Sanchez-Choliz et al. [44].

According to Stone [50], a SAM model is a representation of all the transactions made in the setting of an economy in a certain period of time. The Input–Output Tables define the relation between the final demand and production, whereas the SAM describes how the productive process influences and determines the demand. Thus, SAM extend the Leontief model and the relations shown by the Input–Output Tables as they describe the flows between the value added and the final demand and therefore, represent the circular flow of the income. The SAM describes an economy in great detail although some hypothesis related to the behaviour of the economic agents (Fernandez and Gonzalez [21]); their economic environment and the structure of the economy are taking into account. SAM are used as databases that allow to develop a range of multisectorial models (Shoven and Whalley [47]).

Computable general equilibrium model

A static CGE model involves a set of equations that reflect equilibrium conditions and the behaviour of the different economic agents. For that reason, the producers, the consumers, the public sector and the foreign sector are considered in general terms as follows.

Production

The model for the Andalusian economy incorporates 14 productive sectors. It is assumed that each productive sector generates a homogeneous product, according to a nested production function. At the first nested level, following the Armington hypothesis, the total production of each sector (Q_j) is obtained as a Cobb–Douglas aggregate of domestic output (Qd_j) and imports (Qm_j),. At the second level, the domestic production for each sector is obtained with a fixed-coefficients technology between intermediate inputs (X_{ij}) and value added (VA_j). Finally, at the third nested level, the value added of each sector is obtained by combining the primary factors of capital (K_j) and labour (L_j), according to a Cobb–Douglas technology function. The expressions used at these three levels are given in Eqs. (1)–(3), respectively:

$$Q_j = \beta_{Aj}\, Qd_j^{\delta dj}\ \ Qm_j^{1-\delta dj} \tag{1}$$

$$Qd_j = \min\{X_{1j}/a_{1j}, X_{2j}/a_{2j}, \ldots, X_{14j}/a_{14j}, VA_j/v_j\} \tag{2}$$

$$VA_j = \beta_j K_j^{\alpha_j} L_j^{1-\alpha_j}, \quad j = 1, 2, \ldots, 14 \tag{3}$$

In these expressions, β_{Aj} and β_j are scale parameters; δd_j are parameters which reflect the share of domestic output of j in j's total production; parameters a_{zj} express the minimum amount of z needed to obtain a unit of j; v_j is the technical coefficient of value added; and, finally, α_j and $(1-\alpha_j)$ are parameters which represent the participation of the primary factors, capital and labour, with regard to value added.

Finally, it is assumed that firms obtain their demand functions for inputs and supplies of outputs by maximising profits under these technological constraints.

Consumption

The model assumes only a representative consumer (h). The following Cobb–Douglas utility function (U), defined in terms of saving and consumption, is considered:

$$U = \sum_{j=1}^{14} \gamma_j \ln C_j + \gamma_s \ln S \tag{4}$$

In Eq. (4), the parameters γ_j and γ_s reflect the share of disposable income for goods j and/or for private savings. S represents the saving and Cj expresses the private consumption of good j. Recall that the economy is divided into 14 sectors.

Inequality (5) shows the budget constraint for this representative consumer:

$$\sum_{j=1}^{14} p_j(1 + vat_j)C_j + p_i S = \sum_{j=1}^{14} p_j^F C_j + p_i S \leq YD \tag{5}$$

The sum on the left hand side is the expenditure on final consumption. The parameter vat_j is the value added tax rate for the good j, and p_j^F is its final consumption price inclusive of taxes. Private saving is also included in the expression, being valued at the saving/investment price, p_i.

The right hand side of the inequality (5) shows disposable income, YD. This income comes from the sale of its endowments of capital (K) and labour (L), at the prices r and w, respectively. In addition, consumers receive transfers from the public sector (TPS), indexed by the consumer price index (cpi), and receive transfers from the foreign sector (TFS), although their total quantitative importance is minimal. Finally, consumers have to pay employees' social contributions and income tax, whose rates are ess and τ, respectively.

Thus, the disposable income of the only consumer representative is given by (6):

$$YD = (1-\tau)[rK + wL(1-u) + cpi\ \ TPS + TFS - ess\ \ wL(1-u)] \tag{6}$$

where, u is an endogenous variable that reflects the unemployment rate.

The representative consumer derives the consumption demand functions by maximising the utility function subject to the budget restriction shown in (5).

Government

The activity of the government consists first on the production of public services, by using the technology of “Non-sales oriented services” (j_{14}), while, second, on the demand of public services (public consumption, $C^G j_{14}$) and investment goods (C_i^G). In this sense, this agent can be considered to maximise a Leontief utility function (U^G), defined by (7):

$$U^G = \min\{C^G_{j14},\ \gamma^G C_i^G\} \tag{7}$$

where γ^G is an economic policy parameter reflecting the existence of a fixed proportion between public consumption and public investment.

The budget constraint that the government confronts can be expressed by inequality (8):

$$p_{j14}C^G_{j14} + p_i C_i^G \le R^G + p_i w_i^G - cpi\ TPS \tag{8}$$

The left hand side of this inequality reflects government spending on consumption and investment. On the right hand side, tax revenues are (R^G), from which transfers paid to consumers have to be subtracted (*cpi TPS*) and the stock of debt that the government issues when it is in budgetary deficit and valuated at the same price as saving/investment, p_i ($p_i w_i^G$).

With respect to the total tax revenues R^G, the model includes as indirect taxes: net taxes on production (a), employers' social contributions (b), import taxes (c) and the previously mentioned value added tax (d). As direct taxes, employees' social contributions (e) and income tax (f) are considered. The tax revenue components (a) to (f) are specified in Eqs. (9) to (14), respectively:

(a) Taxes on production (*Rt*):

$$Rt = \sum_{j=1}^{14} t_j \left[\sum_{z=1}^{14} p_z X_{zj} + w(1 + esc_j)L_j + rK_j \right] \tag{9}$$

That is, the domestic output of each sector is subject to a tax at a rate t_j. The production price for sector z is p_z. Finally, esc_j stands for the employers' social contributions rate.

(b) Employers' social contributions (*Resc*):

$$Re\,sc = \sum_{j=1}^{14} esc_j\, w\, L_j \tag{10}$$

(c) Import taxes (*Rtarif*):

$$Rtarif = \sum_{j=1}^{14} tarif_j\, p_m\, Qm_j \tag{11}$$

$tarif_j$ is the import tariff rate for sector j, while p_m is the weighted price index of imported products.

(d) Value added tax (*Rvat*):

$$Rvat = \sum_{j=1}^{14} vat_j\, p_j\, C_j \tag{12}$$

(e) Employees' social contributions (*Ress*):

$$Ress = ess\ w\ L\,(1-u) \tag{13}$$

(f) Income tax ($R\tau$):

$$R\tau = \tau[rK + wL(1-u) + cpi\ TPS + TFS - ess\ wL(1-u)] \tag{14}$$

Eqs. (9) to (14) show the taxes included in the model benchmark.

Foreign sector

The model considers only one foreign sector, being a combination of the rest of Spain, the European Union and the rest of the world:

$$ROWD = \sum_{j=1}^{14} tarif_j \quad Qm_j - TFS - \sum_{j=1}^{14} tarif_j Qx_j \tag{15}$$

where Qm_j represents the sector j imports, Qx_j the sector j exports and *TFS* the transfers which come from the foreign sector to the representative consumer h. The foreign deficit or surplus is represented by *ROWD*.

Labour market

Capital and labour demands are obtained from conditional factor demand functions, thus minimizing the cost of obtaining value added. For the capital factor, we assume perfectly inelastic supply and therefore this factor is always fully employed. However, the model allows possible rigidities in the labour market, so the unemployment rate may be positive. More precisely, we consider the relationship in Eq. (16) between the real wage and the unemployment rate:

$$\left(\frac{w}{cpi}\right) = \left(\frac{1-u}{1-u_0}\right)^{1/\beta_d} \tag{16}$$

This formulation of the labour market in CGE modelling is due to Kehoe et al. [26], following the precepts established in Oswald [33]. The variable (w/cpi) represents the real wage; u is the unemployment rate; u_0 is a parameter that reflects the unemployment rate in the benchmark equilibrium; and β_d is a parameter that expresses the sensitivity of the real wage to the unemployment rate.

This last parameter can have values between zero and infinity. The calculations have carried out using as an average value for the labour market elasticity $\beta_d = 1$.

Equilibrium

The notion of equilibrium used in this model is that of the Walrasian competitive equilibrium, extended to include not only producers and consumers, but also the government and foreign sectors (see, for instance, Shoven and Whalley [47]). A short-run version has been chosen in order to capture the overall effects of the investment, with a given technology, in order to obtain a better sensitivity of the results, following an impact assessment of a special public policy for the renewable energies. Specifically, economic equilibrium is determined by a price vector, an activity-level vector and a set of macro variables so that supply equals demand in all markets, with the sole exception of the labour market, as previously mentioned. Further, each one of the economic agents included in the model attains its corresponding optimal choices under the respective budget constraint, i.e., the agents implement their optimal equilibrium solutions.

Final demand includes the following sectors: consumption—households, investment—firms, public expenditure—government and exports. We consider 14 types of goods – which correspond to the 14 sectors – and one representative consumer who demands certain goods. The rest of his disposable income is saved. The purchase is financed with revenues from the sale of his initial factors endowment. All this is summarized in Eq. (17):

$$\begin{aligned} YD &= \text{Gross income} - \text{Total direct taxes} \\ YD &= wL(1-u) + rK + cpi\ TPS + TFS - (rK + cpi\ TPS + TFS) \\ &\quad - [wL(1-u) - ess\ w\ L(1-u)] - ess\ w\ L(1-u) \end{aligned} \tag{17}$$

where w and r represent labour and capital prices, respectively, and *cpi* is a price index.

With respect to investment and saving has to be mentioned that a ‘*saving driven model* is used, which means that the closure equation of the model is defined by making investment (INV) exogenous. This implies that saving will be defined by the utility function of consumer who is modelled by a Cobb–Douglas

Table A1
Assumed distribution of the investment costs to the economic sectors included in the SAMAND08.
Source: Own elaboration. Figures are distribution percentages.

Sector code		Energy plant and boilers	Civil works	Reesterification plant+glycerin	Tanks and auxiliary equipment	Terrains
1	Agriculture, farm and forestry and fishing					13
5	Electricity					11
8	Food, textile and leather, woods products, chemicals and other manufactures	3		16.83	9	
9	Mining and steel			14.85	20	
10	Metallic products, machinery and vehicles	72	5	35.64	65	
11	Building materials		35	12.87		
12	Transport and transport and communications	5		4.95	4	
13	Construction, commerce and repairing, rest of commerce, sales services and other services	20	60	14.85	2	54

Table A2
Assumed distribution of the O&M (Operation and Maintenance) and other costs to the economic sectors included in the SAMAND08 (excluding salaries).
Source: Own elaboration. Figures are distribution percentages.

Sector code		Insurance	Oil expenses	Financial	Chemicals	Water Steam	Electricity	Maintenance Esterification
1	Agriculture, farm and forestry and fishing		77					
3	Rest of extracts		20					
5	Electricity						100	
7	Water					100		
8	Food, textile and leather, woods products, chemicals and other manufactures				100			22.76
10	Metallic products, machinery and vehicles							37.18
11	Building materials							4.45
12	Transport and transport and communications		3					13.35
13	Construction, commerce and repairing, rest of commerce, sales services and other services	100		100				22.25

technology in his choice and allowing that deficits – public (PD) and foreign (ROWD) – will be determined in an endogenous way:

$$\sum_{j=1}^{14} INV_j p_i = p_i S + PD + ROWD \tag{18}$$

Finally, we assume the total use of the initial factor endowments, although in the case of labour factor, the models include unemployment. Additionally, the level of activity of government and the foreign sectors will be fixed, allowing relative prices, sectors' activity levels, public deficit and foreign deficit work as endogenous variables as mentioned before.

From this, the equilibrium will be an economic state in which the representative consumer will maximize his utility, the firms will maximize their profits after taxes and the public revenues will be equal to the payments of the different economic agents. In this equilibrium, total sales will be equal to total demands in every market.

Annex II

See Tables A1 and A2.

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